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Patent Application of

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for

TITLE: APPARATUS AND METHOD FOR FOCUSING IONS AND CHARGED PARTICLES AT ATMOSPHERIC PRESSURE

GOVERNMENT SUPPORT

The invention described herein was made in the course of work under a grant from the Department of Health and Human Services, Grant Number: 1 R43 RR143396-1.

BACKGROUND—FIELD OF INVENTION

This invention relates to methods and devices for improved collection and focusing of ions generated at atmospheric pressure for introduction into the mass spectrometer and other particle detectors.

BACKGROUND—DESCRIPTION OF PRIOR ART

The generation of ions at atmospheric pressure is accomplished by a variety of means; including, electrospray (ES), atmospheric pressure chemical ionization (APCI), atmospheric pressure matrix assisted laser desorption ionization (MALDI), discharge ionization, ^{63}Ni sources, inductively coupled plasma ionization, and photoionization. A general characteristic of all atmospheric sources is the dispersive nature of the ions once produced. Needle sources such as electrospray and APCI disperse ions radially from the axis in high electric fields emanating from needle tips.

Aerosol techniques disperse ions in the radial flow of gases emanating from tubes and nebulizers. Even desorption techniques such as atmospheric pressure MALDI will disperse ions in a solid angle from a surface. The radial cross-section of many dispersive sources can be as large as 5 or 10 centimeters in diameter. As a consequence of a wide variety of dispersive processes, efficient sampling of ions from atmospheric pressure sources to small cross-sectional targets or through small cross-sectional apertures and tubes (usually less than 1mm) into a mass spectrometer becomes quite problematic. This is particularly amplified if the source on ions is removed from the regions directly adjacent to the aperture.

The simplest approach to sampling dispersive atmospheric sources is to position the source on axis with a sampling aperture or tube. The sampling efficiency of simple plate apertures is generally less than 1 ion in 10^4. Devices developed by Fite (US 4,209,696) used pinhole apertures in plates with electrospray. Devices developed by Laiko and Burlingame (WO 99/63576) used aperture plates with atmospheric pressure MALDI. An atmospheric pressure source by Kazuaki et al (JP04215329) is also representative of this inefficient approach. This general approach in severely restricted by the need for precise aperture alignment and source positioning and very poor sampling efficiency.

A wide variety of source configurations utilize conical skimmer apertures in order to improve collection efficiency over planar devices. This approach to focusing ions from atmospheric sources is limited by the acceptance angle of the field generated by the cone. Generally, source position relative to the cone is also critical to performance, although somewhat better than planar apertures. Conical apertures are the primary inlet geometry for commercial ICP/MS with closely coupled and axially aligned torches. Examples of conical-shaped apertures are prevalent in ES and APCI (US 5,756,994), and ICP (US4,999,492) inlets. As with planar apertures, source positioning relative to the aperture is critical to performance and collection efficiency is quite low.

One focusing alternative utilizes a plate lens with a large hole in front of an aperture plate or tube for transferring sample into the vacuum system. The aperture plate is generally held at a high potential difference relative to the plate lens. The

configuration creates a potential well that penetrates into the source region and has a significant improvement in collection efficiency relative to the plate or cone apertures. This configuration has a clear disadvantage in that the potential well resulting from the field penetration is not independent of ion source position, or potential. High voltage needles can diminish this well. Off-axis sources can affect the shape and collection efficiency of the well. Optimal positions are highly dependent upon both flow (gas and liquid) and voltages. They are reasonable well suited for small volume sources such as nanospray. Larger flow sources become less efficient and problematic. Because this geometry is generally preferential over plates and cones, it is seen in most types of atmospheric source designs. We will call this approach the "Plate-well" design which is reported with apertures by Labowsky et al. (US 4,531,056), Covey et al. (US 5,412,209) and Franzen (US 5,747,799). There are also many Plate-well designs with tubes reported by Fenn et al. (US 4,542,293), Goodley et al. (US 5,559,326), and Whitehouse et al. (US6,060,705).

Several embodiments of atmospheric pressure sources have incorporated grids in order to control the sampling. Jarrell and Tomany (US 5,436,446) utililized a grid that reflected lower mass ions into a collection cone and passed large particles through the grid. This modulated system was intended to allow grounded needles and float the grid at high alternating potentials. This device had limitations with duty cycle of ion collection in a modulating field (non-continuous sample introduction) and spacial and positioning restrictions relative to the sampling aperture. Andrien et al (US6,207,954 B1) used grids as counter electrodes for multiple corona discharge sources configured in geometries and at potentials to generated ions of opposite charge and monitor their interactions and reactions. This specialized reaction source was not configured with high field ratios across the grids and was not intended for high transmission and collection, rather for generation of very specific reactant ions. An alternative atmospheric pressure device by Yoshiaki (JP10088798) utilized hemispherical grids in the second stage of pressure reduction. Although the approach is similar to the present device in concept, it is severely limited by gas discharge that may occur at low pressures if higher voltages are applied to the

electrodes and most of the ions are lost at the cone-aperture from atmospheric pressure into the first pumping stage.

Grids are also commonly utilized for sampling ions from atmospheric ion sources utilized in ion mobility spectrometry (IMS). Generally, for IMS analysis ions are pulsed through grids down a drift tube to a detector as shown in Kunz (US6,239,428B1). Great effort is made to create planar plug of ions in order to maximize resolution of components in the mobility spectrum. These devices generally are not continuous, nor do they require focusing at extremely high compression ratios.

SUMMARY

A preferred embodiment of the invention is the configuration of a High Transmission Element (HTE) comprising a conducting meshed-surface in the shape of a partial hemisphere. The HTE is configured downstream from any of a variety of atmospheric pressure sources and upstream from an Inner Field-shaping Electrode and a conducting collector surface (aperture plate or tube). Ions generated in a relatively large volumetric area of an atmospheric pressure source are attracted toward the HTE by an attracting potential relative to the source region.

The field ratio, the field strength on the source side of the high transmission element relative to the collector side is maintained at a lower value (generally 2-10x less) than the field strength equidistant to the collector side of the HTE. In this operating condition, the field from the collector side of the HTE penetrates into the source side of the HTE and accelerates appreciably all of the ions through the openings in the HTE surface. Typically the field ratio value is calculated at a distance of several opening diameters away from the surface. A good value of a field ratio is greater than 10.

The HTE is typically manufactured so to allow ions to pass easily through the HTE surface. This entails having a HTE with a low depth aspect ratio, referring to the ratio of the dimension of the openings to the thickness of the HTE surface; where the thickness of the element is as thin as mechanically possible. In addition, the openness of the HTE is also important. Typically the openness, the ratio of the dimension of the opening to the entire surface area should be as large as possible to

allow the field from the collector side to penetrate through the HTE into the source side several opening diameters away from the surface of HTE.

The HTE and the inner field-shaping electrode are held at approximately the same potential relative to the collector surface which is held at extremely high potential difference to attract virtually all ions that cross the HTE, through a relatively large aperture in the inner field-shaping electrode, onto the collector surface (or through an aperture into the vacuum). The combination of HTE shape, Inner Field-shaping Electrode aperture size, and potential difference (between the HTE and the collector) affect substantial compression of the dispersed ions into a small cross-sectional beam at the collector. When this beam is precisely aligned with a vacuum sampling aperture into a mass spectrometer, very high sensitivities are achieved.

The physical separation of ionization source region from the deep potential-well focusing region by the HTE solves many of the efficiency problems associated with conventional approaches to ion collection at atmospheric pressure. With the present invention, dispersed ions are not required to be focused to a small diameter in the ion source region, rather, they are required to drift toward a relatively large surface of the HTE. In this way all ions from a given source can be collected across an appropriately sized and shaped HTE surface, then focused in the high field of the focusing well.

One advantage of the present device is the independence of collection efficiency from source position. Multiple sources are able to be uniformly collected with this invention. Multiple focal points can also be configured if there is need to collect part of the sample and analyze another part.

A primary object of the invention is to collect all the ions, all the time.

OBJECTS AND ADVANTAGES

One object of the present invention is to increase the collection efficiency of an ions and/or charged particles at a collector, or through an aperture or tube into a vacuum system, by creating a very small cross-sectional area beam of ions and/or charged particles from highly dispersed atmospheric pressure ion sources. Another object of the present invention is to increase the transmission efficiency of ions from atmospheric pressure ion sources to a target collector, or through an aperture or

tube. The present invention has a significant advantage over prior art in that the use of a High Transmission Element to separate ion generation from ion focusing allows precise shaping of fields in both regions. Ions can be generated in large ion source regions without losses to walls. Droplets have longer time to evaporate and/or desorb ions without loss from the sampling stream. Source temperatures can be lower because rapid evaporation is not required. This can prevent thermal decomposition of some labile compounds. Counter electrodes for electrospray needles do not have to be the plate lens as practices with most convention sources or even the HTE. The aerosol can be generated remotely and ions can be allowed to drift toward the HTE.

Another object of the present invention is to have collection efficiency be independent of ion source position relative to the collection well. With the present invention there is no need for precise mechanical needle alignment or positioning relative to collectors, apertures, or tubes invention. Ions generated any at position in the ion source region are transmitted to the collector, aperture, or tube with similar efficiency. No existing technology has positional independence of the source. The precise and constant geometry, and alignment of the focusing well with sampling apertures will not change with needle placement. The fields inside (focusing side) the well will not change, even if they change outside (source side).

Another object of the present invention is the independence of ion source type. This device is capable of transmission and collection of ions from any atmospheric (or near atmospheric) source; including, electrospray, atmospheric pressure chemical ionization, atmospheric pressure MALDI (laser desorption), inductively coupled plasma, discharge sources, nickel 63 sources, spray ionization sources, induction ionization sources and photoionization sources. The device is also capable of sampling ions of only one polarity at a time, but with extremely high efficiency.

Another object of the present invention is to efficiently collect and/or divert a flow of ions from more than one source. This can be performed in a simultaneous fashion for introduction of mass calibrants from a separate source and analytes from a different source; conversely, it can be performed sequentially as is typical with

multiplexing of multiple chromatographic streams introduced into one mass spectrometer.

Another object of the present invention is to efficiently transmit ions to more than one target position. This would have the utility of allowing part of the sample to be collected on a surface while another part of the sample is being introduced through an aperture into a mass spectrometer to be analyzed.

Another object of the present invention is to improve the efficiency of multiplexed inlets from both multiple macroscopic sources and micro-chip arrays, particularly those developed with multiple needle arrays for electrospray. Position independence of this invention make it compatible with a wide variety of needle array technologies and multi-well plates for surface desorption techniques.

Another object of the present invention is to remove larger droplets and particles from aerosol sources with a counter-flow of gas to prevent contamination of apertures, tubes, and vacuum components.

DRAWING FIGURES

In the drawings, closely related figures have the same number but different alphabetic suffixes.

Figs 1 are cross-sectional illustrations of hemispherical-shaped high transmission element configurations with three alternative target collector elements; namely, (A) the target collector elements configured with an aperture into a vacuum system, (B) the target collector element configured with a tube inlet to a vacuum system, and (C) the target collector element configured with an aperture directed toward a non-vacuum ion sample collector plate.

Figs 2 are cross-sectional illustrations of hemispherical-shaped high transmission element configurations with multiple sources of ions, (A) showing two continuous sources of ions, (B) showing time-varying or pulsed sources of ions from MALDI, and (C) showing time-varying sources of ions from electrospray.

Figs 3 are cross-sectional illustrations of hemispherical-shaped high transmission element configurations as a rotating valve assembly for discretely sampling multiple ion sources; (A) showing valve position 1, and (B) valve position 2.

Fig 4 is a cross-sectional illustration of a two-target array of hemispherical shaped high transmission elements sampling one source of ions.

Figs 5 are cross-sectional illustrations of hemispherical shaped high transmission elements with a counter flow of gas; (A) showing counter-flow of gas at the target region, and (B) showing counter-flow of gas at across the entire area of the high transmission element.

Figs 6 show perspective views of six hemispherical shaped high transmission elements; showing (A) circular apertures, (B) woven mesh, (C) criss-cross mesh (D) hexagonal apertures, (E) transverse slots, and (F) radial slots.

Figs 7 show cross-sectional illustrations various geometries of high transmission element that create effective focusing; (A) planar, (B) conical, and (C) hemispherical.

REFERENCE NUMBERS IN DRAWINGS

20	laser beam	40	high transmission element
21a	first liquid inlet	41	holes or apertures
21b	second liquid inlet	42	ring insulator
22a	first MALDI sample	42a	ring insulator
22b	second MALDI sample	42b	ring insulator
23a	first electrospray liquid cone-jet	44	inner field shaping electrode
23b	second electrospray liquid cone-jet	44a	inner field shaping electrode
		44b	inner field shaping electrode
24	MALDI sample plate	46	ring insulator
25	electrospray needle array	46a	first ring insulator
30	ion source region	46b	second ring insulator
30a	first ion source region	48a	first insulator
30b	second ion source region	48b	second insulator
32	ion collection region	50	ion focusing-steering region
32a	first ion collection region	50a	first ion focusing-steering region
32b	second ion collection region		
34	ion trajectory lines	50b	second ion focusing-steering region
36	outer field shaping electrode		

52	gas supply line
56	equipotential lines
70	insulated tube or capillary
72	rotating switch
74	isolation plate
76	axial valve aperture
78	off-axis valve aperture
80	target collector element
81	electrode
80a	first target collector element
80b	second target collector element
82	collector surface
82a	first off-axis collector element
82b	second off-axis collector element
84	target collection aperture
84a	tubular target collection aperture
86	inner field-shaping electrode aperture
86a	inner field-shaping electrode aperture
86b	inner field-shaping electrode aperture
86c	inner field-shaping electrode aperture
86d	inner field-shaping electrode aperture
86e	inner field-shaping electrode aperture
86f	inner field-shaping electrode aperture
90	collector region
90a	first collector region
90b	second collector region
92a	first off-axis collector region
92b	second off-axis collector region
94	collector plate

DESCRIPTION

Preferred Embodiment- Figs 1A and 6A (Basic Focusing Device)

One embodiment of the present invention is an ion or particle focusing device utilizing a high transmission element **40** as illustrated in Fig 1A. The device includes an atmospheric pressure or near atmospheric pressure ion source region **30** from which ions are supplied to an ion collection region **32**. This device is intended for use in collection and focusing of ions from a wide variety of ion sources; including, but not limited to electrospray, atmospheric pressure chemical ionization, photo-ionization, electron ionization, laser desorption (including matrix assisted), inductively coupled plasma, and discharge ionization. Both gas-phase ions and charged particles emanating from region **30** are collected and focused with this device. Ions and charged particles from region **32** move through a high transmission element **40** into an ion focusing-steering region **50**. Strong electric fields in region **50** relative to region **32** cause ions in region **32** to traverse element **40** and be focused to a target collector element **80**. Movement of ions from region **30** to region **90** is indicated by a set of ion trajectory lines **34**. The focused ions at element **80** are transferred to an ion collection region **90** through a target collection aperture **84**. Aperture **84** has a diameter appropriate to restrict the flow of gas from region **50** to region **90**. In the case of vacuum detection, such as mass spectrometry in region **90**, typical aperture diameters are 100 to 500 um. Element **80** is made of a conducting material or a conductively coated insulating material such as glass. The collection region **90** in this embodiment is intended to be the vacuum system of a mass spectrometer (interface stages, optics, analyzer, and detector) or other low-pressure ion and particle detectors. In this embodiment the element **40** has a hemisphere-shaped surface of uniform cross-section (Fig 6A). It is made of a conductive material, such as stamped sheet metal. Circular-shaped apertures or holes **41** are evenly spaced across element **40**. Element **40** is fabricated from a conducting and chemically inert material such as stainless steel. It is also possible to use molded materials that are conducting as well as non-conducting molded materials with subsequent deposition of conducting material on the surface of element **40**. An inner field-shaping electrode **44** is a conducting circular plate position between element **40** and **80**. Element **40** is

electrically separated from electrode **44** by insulating ring **46**. Element **80** is electrically separated from electrode **44** by insulating ring **42**. An outer field-shaping electrode **36** comprises a conducting cylinder coaxial to and outside of element **40**. Electrode **36** is electrically separated from element **40** by insulating ring **46**. All elements and electrodes are generally made of chemically inert and conductive materials that may be stamped or machined to conform to the appropriate geometries, such as stainless steel, brass, copper, and aluminum.

Additional Embodiments- Figs 1B, 1C, 2A, 2B, 2C - (Alternative Target Collectors, Multiple Sources)

Additional embodiments are shown in Figs 1B, 1C, and 2A through 2C, in each case the high transmission element **40** is shown with a hemispherical surface.

- In Fig 1B the ion and particle focusing device shows a similar arrangement as in Fig 1A, however the plate-shaped collector electrode **80** is replaced by tube-shaped target collector element **80** which is located on the outside of an electrically insulated tube **70**. Flow of ions and particles through tube **70** and tubular target collector aperture **84a** are similarly transferred to collector region **90**. Region **90** is generally the vacuum region of a mass spectrometer or other vacuum detectors. Movement of ions from region **30** to region **90** is indicated by a set of ion trajectory lines **34**.
- In Fig 1C the ion and particle focusing device also shows a similar arrangement as in Fig 1A, however, this configuration represents the collection of focused ions onto a target surface of a sample plate or probe. In this embodiment, region **90** is replaced with a collector plate **94.** The focused ions at element **80** are transferred to plate **90** through a target collection aperture **84**. Aperture **84** has a diameter appropriate to restrict the flow of gas from region **50** to plate **94**, particularly in the case of reduced pressure ion collection. Plate **94** has the purpose of collecting ions, such as, but not limited to a 96-well plate, the collector surface **82** of which is electrically conductive. Note that the entire plate **94** could be made of conductive material negating the need for surface **82**. Movement of ions from region **30** to plate **94** is indicated by a set of ion trajectory lines **34**.

- In Fig 2A, a single element **40** is downstream of two discrete separate ion collection regions **32a** and **32b** which are downstream of ion source regions **30a** and **30b**, respectively. Movements of ions from regions **30a** and **30b** to region **90** are indicated by a set of ion trajectory lines **34**. This device allows the efficient sampling of two discrete ion source regions from two unique locations. Sampling of multiple ion sources is not limited to two regions; but three, four, five, or more may be sample through a single focal point (element **80**).
- In Fig 2B, a single element **40** is downstream of an atmospheric pressure matrix assisted laser desorption ionization (MALDI) sample plate **24**, shown at two discrete ion sampling times. At (Time 1) a first sample **22a** is illuminated by laser **20** producing desorbed ions in ion source region **30a.** At (Time 2) a second sample **22b** is illuminated by laser **20** producing desorbed ions in ion source region **30b**. Ions from both regions **30a** and **30b** are collected across a single element **40** and passed through aperture **84** to collection or mass analysis in region **90**.
- In Fig 2C, a single element **40** is downstream of an electrospray needle array **25** at two different time points. At (Time 1) an electrospray source **21a** forms a liquid cone-jet **23a** and produces an aerosol of highly charged liquid droplets and ions in ion source region **30a.** At (Time 2) a second electrospray source **21b** forms a liquid cone-jet **23b** producing an aerosol of highly charged liquid droplets and of ions in ion source region **30b**. Ions from both regions **30a** and **30b** are collected across a single element **40** and passed through aperture **84** to collection or mass analysis in region **90**.

Alternative Embodiments- Figs 3, 4, 5A, 5B, 6B, 6C, 6D, 7A, 7B, 7C (Ion Switching Valve, Multiple Targets, Counter-Flow Gas)

There are a variety of alternative embodiments of the present invention in terms of accommodating multiple ionization sources and multiple collectors (type and number). In addition, the device is capable of accommodating various geometries of element **40** (Figs. 7), and accommodating a wide variety of possible aperture types for element **40** (Figs. 6).

- Figs 3 show a high efficiency atmospheric pressure focusing device operating in an ion valve-switching configuration. Here two discrete and continuous ion sources **30a** and **30b** are shown. Ions from each source are continually being sampled across element **40** into focusing regions **50a** and **50b** respectively. The hemisphere-shaped element **40** is partitioned in half by isolation plate **74** separating regions **50a** and **50b** and allowing ions from each source to be collected and focused uniquely. A rotating switch **72** is rotated about the axis of tube **70** to present an axial valve aperture **76** to region **50a** and an off-axis valve aperture **78** to region **50b** in valve (Position 1) show in Fig 3A. Switch **72** is rotated 180° about the axis of tube **70** to present aperture **76** to region **50b** and aperture **78** to region **50a** in valve (Position 2) show in Fig 3B. In valve (Position 1), ions from region **32a** are focused toward element **80** through aperture **76** and sampled into region **90** for collection or mass detection. In this position, the ions from region **32b** are focused toward a second off-axis collector element **82b** through aperture **78** and collected or discarded into a second off-axis collector region **92b**. In valve (Position 2), ions from region **32b** are focused toward element **80** through aperture **76** and sampled into region **90** for collection or mass detection. In this position, the ions from region **32a** are now focused toward a first off-axis collector element **82a** through aperture **78** and collected or discarded into a first off-axis collector region **92a**. In this embodiment, the field shaping electrodes **44a** and **44b** comprise the surface of the rotating switch **72**. Electrode **36** is isolated from element **40** by insulator **46**. Element **80** is isolated from switch **72** by insulator **42**. Elements **82a** and **82b** are insulated from switch **72** by insulators **48a** and **48b**, respectively. It is the intent of Fig 3 to illustrate a two-position ion valve switching configuration; however, four, six, eight, and larger position valves using additional off-axis valve apertures and partitioning plates will accommodate additional ionization sources for multiplexing applications. Rotation and aperture positioning would be 90°, 60°, and 45°, respectively.
- In Fig 4, a single source **30** supplies ions to two discrete focusing regions. Part of the ions from region **30** traverse element **40a** and are focused in region **50a** toward element **80a** to collection region **90a**. Conversely, another portion of the

ions from region **32** traverse element **40b** and are focused in region **50b** toward element **80b** to collection region **90b**. The object of this embodiment is the transfer of ions to more than one target. More than one target could entail multiple detectors, one in region **90a** and one in region **90b**. Alternatively, there may be applications where ions (e.g. proteins, reagents) from one source may be required to be collected in two or more focal points such as the wells of multiple sample trays (e.g. 96-well plates). This device can supply efficient and real-time sample splitting for micro-collection.

- In Fig 5A the ion and particle focusing device shows a hemisphere-shaped element **40** in the same manor as Fig 1A with the addition of a flow of gas counter to the direction of motion of ions and charged particles (trajectory lines **34**). The gas is introduced from an external gas supply through tube **52** into the space between electrode **44** and element **80**. The counter-flow of gas travels through an inner field-shaping electrode aperture **86**, across region **50**, traversing element **40** into region **32**. The relative diameter of aperture **86** is significantly larger than aperture **84**. The counter-flow gas is generally composed of, but not limited to nitrogen.
- In Fig 5B the ion and particle focusing device shows a hemisphere-shaped element **40** in the same manor as Fig 1A with the addition of a flow of gas counter to the direction of motion of ions and charged particles. The gas is introduced from an external gas supply through tube **52** into the space between electrode **44** and element **81**. The counter-flow of gas travels through an array of apertures **86a**, across region **50**, traversing element **40** into region **32**. This counter-flow configuration has as an object the removal of a much broader area of interfering gases and particles. The relative diameters of apertures **86a** are significantly larger than aperture **84a**. The counter-flow gas is also generally composed of, but not limited to nitrogen.
- Fig 6B shows a hemisphere-shaped element **40** made of single strands of metal wire woven to produce a pattern of square openings, commonly referred to as a plain square weave;

- Fig 6C shows a hemisphere-shaped element **40** made of two sets of single strands of metal wire with equal diameters, one set overlaying the other, producing a pattern of square openings;
- Fig 6D shows a hemisphere-shaped element **40** made of a surface with apertures **41** fabricated in a manner to produce a pattern of hexagon-shaped openings;
- Fig 6E shows a hemisphere-shaped element **40** made of a surface with transverse slotted apertures **41** across the surface.
- Fig 6F shows a hemisphere-shaped element **40** made of a surface with radial slotted apertures **41** across the surface.

Alternatively, the element **40** may be manufactured by using the techniques of microelectronics fabrication: photolithography for creating patterns, etching for removing material, and deposition for coating the surfaces with specific materials;

- Fig 7A shows element **40** as a cross-section of a planar-shaped surface of radial slotted apertures **41** as in Fig 6F. Element **40** is attached to the electrode **44** isolated from the planar-shaped collector element **80** by insulator **42**;
- Fig 7B shows element **40** as a cross-section of a cone-shaped surface of radial slotted apertures **41** as in Fig 6F. Element **40** is attached to the electrode **44** isolated from the planar-shaped collector element **80** by insulator **42**; and
- Fig 7C shows element **40** as a cross-section of a hemisphere-shaped surface of radial slotted apertures **41** as in Fig 6F. Element **40** is attached to the electrode **44** isolated from the planar-shaped collector element **80** by insulator **42**.

OPERATION

Operation of the Basic Device (As shown in Figs 1, 5, 6, and 7)

Ions supplied or generated from an atmospheric pressure source are attracted to the high transmission element **40** by an electrical potential difference between the ion source region **30** and the potential on element **40**. The ions will tend to follow the field lines through region **32**. We distinguish regions **30** and **32** in that the ion source region **30** may comprise a plasma with ill-defined or uncontrollable fields. Region **32** contains gas such as air or nitrogen below the threshold for discharge ionization and

fields defined by the shape and potential on element **40**. The ions moving toward element **40** are diverted away from the conducting surfaces of element **40** through apertures **41** by the presence of the electrical field penetrating through element **40** into the part of region **32** that is close to the outer surface of element **40**. This field penetration is due to the requisite field strength on the focusing side of element **40** being larger than the field strength in region **32**. The field in region **50** must be higher than that in region **32**. Under conditions of a high field ratio (field in region **50**/field in region **32**) a significant percentage up to 100% of ions from region **32** are transferred into region **50**. This effectively makes element **40** transparent to ions moving from region **32** to region **50**.

The shape of element **40** and the potential difference between elements **40** and **80** will cause the ions that traversed element **40** to be focused at or near a small cross-sectional area at the center of element **80**. In the operation of this device as an atmospheric inlet to the mass spectrometer, the target collection element **80** will have an aperture **84** through which focused ions will travel on their path into the vacuum system. Both focusing fields and viscous forces will cause ions in the region of aperture **84** to travel into the vacuum system of the mass spectrometer. It is intended that this focusing device be coupled to the vacuum inlet of any conventional mass spectrometer or the atmospheric pressure inlet to any ion mobility spectrometer. Alternatively, this device may be operated as a collection and focusing device to move gas-phase ions and charged particulate materials from diffuse atmospheric sources onto small focal areas of collector surfaces. We envision applications for laying down materials in printing, semiconductor, and micro-chemistry applications. In addition, this device can operate to collect sample onto surfaces for subsequent surface analysis (e.g. depositing sample onto MALDI targets, SIMS targets, or X-ray targets). In addition, collection onto surfaces of reaction wells may allow for gas-phase ion production to be a useful tool for placing charge chemical species into a discrete and small reaction well. This technique could be useful for automated collection and specification of complex reagents and reactant for applications in combinatorial chemistry.

An important alternative-operating mode of this device is illustrated in Figs 5. The flow of gas in a direction that is counter to the movement of ions will serve to reduce or eliminate contamination from particulate materials and neutral gases. The operation with counter-flow of gas is accomplished by adding sufficient flow to purge or remove unwanted materials. This to some extent will have some dependency on the volatility of neutral gases and the size of interfering particulate material originating from the source region **30**. Lower mobility charged particles may also be swept away in the counter-flow of gas.

Operation of the of Multiple Source Devices (As shown in Figs 2 and 3)

The operation of the present invention will accommodate collection of ions from more than one source. The multi-source device operated under the same principles as a single-source device with the addition of more than one source of ions. Multiple sources of ions can be sampled from multiple sources derived from different locations (Fig 2A), derived at different times (Figs 2B & 2C), and controlled through ion valve switching (Figs 3A & 3B). Ions move from their respective source toward element **40** due to the electrical potential difference between the source and element **40** creating attractive forces. High fields from region **50** penetrates the apertures of element **40** to direct the motion of the ions from regions of **32a** and **32b** into the respective regions of **50a** and **50b**. Selection of a specific source of ions to be focused can be accomplished in the time dependent manner by controlling the generation process of ions (e.g. pulse of laser, application of voltage to needle).

There may be operating modes where simultaneous collection of ions from two sources is desirable. An example would be the addition of a mass calibration standard in one source while introducing analytical sample in the other ion source. This simultaneous source application would of course have it primary application in high-resolution mass spectrometry.

There are also noteworthy alternative operating modes of multiple sources in terms of spatial orientation of the ionization source. One configuration may fix the location of the sample and collect ions from differing spatial origins such as illustrated in Figs 2. Alternatively, the samples could be moved so that the location of ion

generation is fixed and the sample is moved (e.g. move the sample plate instead of the laser beam).

An important alternative-operating mode of the multi-source embodiment of this device is found in the ion switch configuration illustrated in Figs 3. The switch is operated by rotating switch **72** about the axis tube **70**. As switch **72** rotates, the alignment of off-axis valve aperture **78** with either element **82a** or **82b** will determine which direction the ions will travel in the two-source configuration. The valve is operated by switching switch **72** back and forth 180° from (Position 1) to (Position 2) thereby selecting either ion source for collection into the mass spectrometer or other collection device. The device does not require off-axis collection in either of regions **92a** or **92b** to be to discard or waste. There may be applications of this device where off-axis collection of diverted materials is important for isolation, purification, or other processing and analysis. The rate of rotation of switch **72** will determine the frequency of discrete sampling. High-speed sampling at many rpm will allow ion sampling at frequencies compatible with conventional chromatographic peak widths for applications in LC/MS or GC/MS. This operation of the present device within LC/MS or GC/MS would of course require that the ion source region be coupled to a chromatographic system. We envision that this is done in the wide variety of conventional configurations, which are not explicitly part of this invention.

Operation of a larger number of sources and valve ports are not illustrated in these figures but would operate in the same fashion as the two-source valve with rotating off-axis apertures spaced around a central sampling aperture.

Operation of the of Multiple Collector or Target Devices (As shown in Fig 4)

This invention may also operate in a mode whereby the ions from a single ion source region **30** are collected and focused across multiple high transmission elements with multiple discrete collection regions. This mode is useful for delivering ions from a single source to multiple focal points. Fig 4 shows the multi-target embodiment with only two targets, **90a** and **90b**. The intent of this disclosure is to describe the application of a single source ion focusing device with two or more high transmission elements and companion targets up to a large array of high transmission elements and target foci which may have application in a wide variety of

applications including loading reagents onto reaction wells, printing, micro-fabrication, and semi-conductor manufacture.